POWER ALLOCATION SCHEME FOR DMT-BASED MODEMS EMPLOYING

SIMPLEX TRANSMISSION

FIELD OF THE INVENTION

5   The present invention relates generally to simplex transmission of signals in a

multicarrier-based modem system, and more particularly to a method and system for allocating

information bits when the power needs to be assigned for Discrete Multi-Tone (DMT)

transmission.

10   **BACKGROUND OF THE INVENTION**

Digital Subscriber Line (DSL) technology greatly increases the digital capacity of an

ordinary telephone line, allowing much more information to be channeled into a home or office.

The speed that a DSL modem can achieve is based on the distance between the home or office

and the central office. Symmetric DSL (SDSL) utilizes a single twisted pair and is typically

15   used for short connections that need high speed in both directions. High Bit Rate DSL (HDSL)

is a symmetric technology that uses two cable pairs and may achieve usable transmission to

12,000 feet. Each twisted pair may be used to provide T1 transmission, but the lines may not be

shared with analog phones. HDSL-2 needs only one cable pair and supports a distance of

18,000 feet. SDSL utilizes only one cable pair and may be used with adaptive rates from 144

20   Kbps to 1.5 Mbps. The DSL technology provides "always-on" operation.

Asymmetric DSL (ADSL), which uses frequencies that are higher than voice, shares

telephone lines and may be used to access the Internet. For ADSL, a Plain Old Telephone

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System (POTS) splitter generally must be installed at the user end to separate the voice

frequencies and the ADSL frequencies. The G.lite version of ADSL, also known as the ADSL

lite, Universal ADSL or splitterless ADSL, gets around the splitter requirement by having all

phones plug into low-pass filters that remove the ADSL high frequencies from the voice

5   transmissions. ADSL is available in two modulation schemes: the Discrete Multi-tone (DMT)

or Carrierless Amplitude Phase (CAP).

In DMT-based DSL modems, the selected bandwidth of 1.104 MHz is divided into bins

and the data bits are used for Quadrature Amplitude Modulation in each bin. During the

initialization period, a channel SNR estimation phase is employed to transmit a known pseudo-

10   random noise (PRN) sequence while the receiver computes the channel characteristics from the

received signal. The characteristics are computed in the form of a $g_k \cdot N_k^{-1}$ ratio, where g_k is the

channel gain (attenuation, $|H(k)|^2$) in frequency band k, and N_k is the noise power in band k.

Prior art has disclosed a number of algorithms for determining the power distribution across the

full frequency bandwidth for maximum data rate. The optimum approach for Additive White

15   Gaussian Noise (AWGN), has been proved to be a 'water pouring' algorithm of power

distribution, where the $g_k \cdot N_k^{-1}$ profile is considered to be equivalent to the 'terrain' and the

available power budget is likened to 'water that is poured' on the terrain. In this analogy, the

water depth at position k is equivalent to the power allocated to the frequency bin k.

The following analysis provides a brief description of this approach. As is known to

20   those skilled in the art, the relationship between the number of bits in a frequency bin and the

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power needed to transmit that number of bits, for a specified bit error rate (BER) at the receiver

for which $g_k \cdot N_k^{-1}$ is the measured channel characteristic, is given by the following expression:

$$b_k = \log_2\left[1 + \frac{3 \cdot g_k' \cdot E_k}{K \cdot (N_k)}\right] \qquad k=1...256 \qquad \text{Eq. 1}$$

where

b_k = No. of bits in frequency bin k

E_k = Power required in bin k to transmit the b_k bits

5 $\dfrac{g_k'}{N_k}$ = Measured channel attenuation to noise power ratio in bin k

N_k = Noise power in bin k

$$K = \left[Q^{-1}\left(\frac{P_e}{N_e}\right)\right]^2 \text{ where } 2 \leq \left[N_e = 4 \cdot \left(1 - \frac{1}{\sqrt{2^{b_k}}}\right)\right] \leq 4 \text{ for } 2 \leq b_k$$

Given the expression in Eq. 1, the power needed to transmit b_k bits in bin k can be obtained by

inverting the expression by ignoring the dependence of N_e on b_k. (Prior art has shown that

approximating N_e by a constant between 2 and 4 has a negligible effect on the overall data

10 capacity.)

$$E_k = \frac{KN}{3g_k'}\left(2^{b_k} - 1\right) = \frac{N}{g_k}\left(2^{b_k} - 1\right) \text{where } g_k = \frac{3g'}{K}$$

The problem of power allocation consists of distributing the available power budget over the

256-bins so that the capacity as defined by $\sum_{k=1}^{256} b_k$ is maximized. The allocation must be

performed within constraints of the DSL modems that are subject to a power mask constraint

15 that limits the maximum power that may be allocated to each bin.

The solution to the 2-tone power allocation problem is known in the art. The available

power is distributed optimally over two bins to maximize the 2-bin capacity of b_1+b_2. In order

to perform the 256-bin power allocation, the prior art proposes an iterative approach to solve the

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"water-pouring" problem. However, such a solution for the 256-bin power allocation results in noisy bins. Thus, there is a need for a method, system and computer medium for assigning data bits to bins for simplex transmission while minimizing noise.

5   **SUMMARY OF THE INVENTION**

The present invention provides a method, apparatus, computer readable medium and modem for allocation of an available power to Discrete Multi-Tone (DMT) frequency tones in a DMT-based Digital Subscriber Line (DSL) modem. The steps typically include: (1) initializing the DMT-based DSL modem by calculating aggregate values of channel attenuation, noise

10   power, and power mask; (2) pre-filtering to flag noisy bins that are unable to support a minimum number of bits with a maximum power available for transmission in a bin; and (3) using a repeated-bisection splitting scheme to allocate the available power substantially optimally among a plurality of bands for DMT frequency tones, where bins flagged in the pre-filtering step are excluded.

15   In one embodiment, the repeated-bisection splitting scheme may include the steps of: splitting the available power optimally between the lower and the upper halves of a 1.104-MHz bandwidth to form two power fractions for two substantially 552 KHz wide bands; splitting each of the two power fractions substantially optimally between two halves of each of the substantially 552 KHz wide bands to form four power fractions for four substantially 276 KHz

20   wide bands; splitting each of the four power fractions optimally between two halves of each of the four substantially 276 KHz wide bands to form eight power fractions for eight substantially 138 KHz wide bands; splitting each of the eight power fractions optimally between two halves

of each of the eight substantially 138 KHz wide bands to form sixteen power fractions for

sixteen substantially 69 KHz wide bands; splitting each of the sixteen power fractions optimally

between two halves of each of the sixteen substantially 69 KHz wide bands to form thirty-two

power fractions for thirty-two substantially 34.5 KHz wide bands; splitting each of the thirty-

5   two power fractions optimally between two halves of each of the thirty-two substantially 34.5

KHz wide bands to form sixty-four power fractions for sixty-four substantially 17.25 KHz wide

bands; splitting each of the sixty-four power fractions optimally between two halves of each of

the sixty-four 17.25 KHz wide bands to form one hundred twenty eight power fractions for one

hundred twenty eight substantially 8.625 KHz wide bands; and splitting each of the one hundred

10   twenty eight power fractions optimally between two halves of each of the one hundred twenty

eight, 8.625 KHz wide bands to form two hundred fifty six power fractions to form two

hundred fifty six substantially 4.3125 KHz wide bands.

The initializing step may include calculating aggregate parameters needed for the

splitting steps while excluding bins flagged in the pre-filtering step.

15   Each of 2^j elements of a noise power vector to be used at step-j may be calculated as a

sum of noise power values in bins aggregated for the step-j, where j =1,..., 8. Each of 2^j

elements of a channel attenuation vector that is to be used at step-j may be calculated as an

average of channel attenuation values in bins aggregated for step-j, where j =1,..., 8. Each of 2^j

elements of a power mask vector that is to be used at step-j may be calculated as a sum of

20   power mask values in bins aggregated for step-j, where j =1,... ,8 .

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The available power may be allocated to 2^n tones where n is a preselected integer. Here, initializing includes calculating aggregate parameter values of channel attenuation, noise power, and power mask for n subsequent steps.

The apparatus of the present invention allocates the available power budget to a plurality

5   of Discrete Multi-Tone (DMT) frequency tones using a repeated-bisection of power scheme to partition the available power over the plurality of DMT frequency tones in a DMT-based Digital Subscriber Line (DSL) modem. The apparatus includes an initialization unit, a pre-filtering unit, and a repeated-bisection power splitting and allocation unit. The initialization unit initializes the DMT-based DSL modem by calculating aggregate parameter values of channel

10 attenuation, noise power, and power mask. The pre-filtering unit is coupled to the initialization unit and is used for pre-filtering to flag noisy bins that are unable to support a minimum number of bits with a maximum power available for transmission in a bin. The pre-filtering step is utilized to ensure that narrow-band energy from radio sources, power lines, and other line-spectrum-producing interferers does not distort the power-allocation process by "wasting"

15 power in bins which overlay these interferers. The repeated-bisection power splitting and allocation unit is coupled to the pre-filtering unit and is used for implementing the repeated bisection of power scheme of the invention to allocate available power substantially optimally among a plurality of bands for DMT frequency tones, where bins flagged by the pre-filtering unit are excluded. Where desired, the initialization unit may receive notification of the flagged

20 noisy bins from the pre-filtering unit and exclude the flagged noisy bins.

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BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary of the invention, as well as the following detailed description of preferred embodiments, is better understood when read in conjunction with the accompanying drawings, which are included by way of example, and not by way of limitation with regard to

5   the claimed invention.

Figure 1 is a schematic representation of steps, splits and frequency bands in a multi-tone power splitting scheme in accordance with the present invention.

Figure 2 is a flow diagram of one embodiment of steps in accordance with the method of the present invention.

10   Figure 3 is a block diagram of a modem having an apparatus for allocation of an available power to Discrete Multi-Tone frequency tones in a Discrete Multi-Tone frequency-based Digital Subscriber Line in accordance with the present invention.

Figure 4 is a flow chart showing two embodiments of steps in accordance with the method of the present invention.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention utilizes a "repeated-bisection" scheme to extend the 2-bin solution to 256-bins instead of using the iterative scheme suggested in the prior art. The prior art considers the simple case in which the power is to be distributed over two bins. The two-bin

20   capacity, $b_1 + b_2$ is maximized with respect to the power to be allocated to bin-1 as (E_r), when the power is E and the power to be allocated to bin-2 is E-E_r. It can be shown that the optimum power allocation to bin 1 is given by the following expression.

$$E_r = \frac{1}{2}\left(E + N_2 \cdot g_2^{-1} - N_1 \cdot g_1^{-1}\right) \qquad \text{Eq. 2}$$

This solution is derived for the two-tone simplex transmission. It is also the water-filling

solution, e.g., if the noise power and attenuation coefficients in the two bins are equal, the two

terms cancel each other and the power is divided equally between the two bins. Similarly, the

5   smaller the ratio of noise power to attenuation coefficient is in bin 1, the larger the value of E_r

is, which in turn, allocates greater power to bin 1. The above expression may be simplified by

denoting $M_i = N_i \cdot g_i^{-1}$ for $i = 1,2$ and $t_{21} = M_2^{-1} - M_1^{-1}$:

$$E_r = 0.5 \cdot \left(E + t_{21}\right) \text{ and } E\text{-}E_r = 0.5 \cdot \left(E - t_{21}\right) = 0.5 \cdot \left(E + t_{12}\right) \qquad \text{Eq. 3}$$

Discrete Multi-tone-based Digital Subscriber Loop (DSL) modems require a scheme for

10   allocating bits and power to the discrete tones during the initialization period. As shown in

Figure 2, the initialization parameters are computed 202, and pre-filtering is used to remove

bins that cannot support the minimum number of bits 204. Then the repeated-bisection splitting

scheme of the present invention partitions available power over all the frequency bins to which

power needs to be assigned for DMT-transmission 206, 208, 210, 210, 212, 214, 216, 218. The

15   power allocation is performed with the objective of maximizing the total data rate.

Extension to Multi-Bins

In the present invention, a repeated bisection scheme is used for extending the two-tone

solution to the 256-tone case. The scheme operates by first bisecting the 1.104 MHz band into

20   halves to solve the first '2-tone' problem. In the second split, two problems, each a different 2-

tone problem, are solved. In split 3, four problems, each a different 2-tone problem, are solved.

This process of progressively splitting each band in halves is continued for 8 splits, until power

is allocated to each of the 256 bins. The repeated bisection scheme 206, 208, 210, 210, 212, 214, 216, 218 is shown schematically in Figures 1 and 2. The number of bands that are produced as a result of split-i is equal to 2^i and the bandwidth of each band at split-i is equal to $\frac{1104}{2^i}$ KHz. Thus, at split 1, each band is 552 KHz wide and at the 8th split, each band

5   corresponds to the DMT frequency bin. Figure 1 also shows the number of 2-tone solutions that must be computed at each split. At split-1, one 2-tone solution generates the partition of the budgeted power over each of two 552 KHz frequency bands. Each of these two power fractions is split into two parts in split-2 to yield power allocations to four 276 KHz frequency bands. Figure 1 shows that the maximum number of 2-tone solutions that may have to be computed is

10   equal to 255. The following explains the procedure for calculating the values of the channel attenuation and noise PSD profiles at each split.

Pre-filtering to eliminate noisy bins

In a pre-filtering step, the invention provides for calculating the number of bits that can be received in a bin with the desired bit error rate (BER), when the tone is transmitted with a

15   power level that is equal to that specified by the power mask value at the frequency bin. If the calculated value is less than the minimum number of bits that can be allocated to that bin, then the bin is flagged for exclusion from the subsequent power allocation steps.

Input power at each split

In the first split, the power budgets allocated are allocated to the two halves. For

20   example, the 0.1-Watt budgeted power would be split between the upper and the lower halves of the entire 1.104 MHz band.

In the second split, the input power to each of the two portions would be the partial power allocated to the corresponding half-band in split 1. For example, if 75 mWatt is assigned to the lower half-band and the rest of the 25 mWatts is allocated to the upper half-band, then the power inputs to the two 2-tone portions is 75 and 25 mWatts, respectively.

5   In the third split, the power input to each of the four portions is the partial power allocated to the corresponding quarter-band in split 2.

As shown in Figure 1, step-8 consists of performing 128 solutions of the 2-bin allocation portions. Thus, split 8 is the only part of the scheme that uses the normal DMT bins. All of the earlier 7 steps require system parameters for progressively wider frequency bands. In fact, the 'tone' to which power is allocated in step-i (i =1…8) is of a bandwidth that corresponds to that of 2^{8-i} frequency bins. Hence, the appropriate channel parameters must be calculated for each step.

$$\text{No. of 2-tone solutions at step-} i = 2^{i-1}$$
$$\text{No. of frequency bands produced at step } i = 2^{i}$$
$$j \underset{\Delta}{} \text{ Band Index at step-} i = 1…2^{i}$$

Noise power at each split

Noise power in band index j should be the total noise power in that band. If N_k represents the noise power in bin k $(k=1…256)$, then the noise power in band j at step i may be calculated as follows and stored for use in the 7-steps of the band-splitting scheme. The calculation of the integrated noise power values needs to be performed just once, and it adds 254-array elements to the storage requirement. Note that the summations for average noise calculation are performed over only those bins that can support at least the minimum number of

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bits with the maximum power that can be allocated to one bin as determined in the pre-filtering

step above.

$$N(i,j) = \sum_{k \in band_j} N_k \quad \text{where,} \quad k = 1 \cdots 2^i \qquad \text{Eq. 4}$$

Channel attenuation parameters at each split

5   The channel attenuation coefficient in bin-k in each band, g_k, is the average value for the

band. The summations for the calculation of average channel attenuation are performed over

only those bins that were not excluded by the pre-filtering step.

$$g(i,j) = \frac{1}{2^{8-i}} \cdot \left(\sum_{k \in band_j} g_k \right) \text{where } j = 1 \cdots 2^i \qquad \text{Eq. 5}$$

10   ### Power mask constraint at each split

The power mask constraint may be applied by calculating the implied mask constraint

for each of the wider bands used in splits 1 through 7. Power mask in band index j should be

the total power mask in that band. If $Pmask_k$ represent the power mask values in bin k

($k=1\ldots256$), then the power mask in band j at step i can be calculated and stored for use in the

15   7-steps of the band-splitting scheme. The calculation of the integrated power mask values

needs to be performed just once, and it adds 254-array elements to the storage requirement. The

ADSL parameters are such that the total integrated power mask exceeds the power budget.

Hence, a signal is not intended to be as large as to reach the power mask at all the frequencies.

Therefore, the integrated values of the power mask for the wider bins are compared with the

20   total power budget and the integrated power mask is set as the minimum of the integrated value

and the total power budget.

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$$Pmask(i, j) = \min\left(\sum_{k \in band_j} Pmask_k, P_{budget}\right) \text{ where } j = 1 \cdots 2^i$$

Figure 3 is a block diagram of a modem 302 having an apparatus 304 for allocating an

available power to a plurality of Discrete Multi-Tone (DMT) frequency tones using a repeated-

5   bisection of power scheme to partition the available power over the plurality of DMT frequency

tones in a DMT-based Digital Subscriber Line (DSL) in accordance with the present invention.

The apparatus 304 includes an initialization unit 306, a pre-filtering unit 308 and a repeated-

bisection power splitting and allocation unit 310. The initialization unit 304 is used for

initializing the DMT-based DSL modem by calculating aggregate parameter values of channel

10   attenuation, noise power, and power mask. The pre-filtering unit 308 is coupled to the

initialization unit 306 and is used for pre-filtering to flag noisy bins that are unable to support a

minimum number of bits with a maximum power available for transmission in a bin. The

repeated-bisection power splitting and allocation unit 310 is coupled to the pre-filtering unit 308

and is utilized for using the repeated-bisection of power scheme to allocate the available power

15   substantially optimally among a plurality of bands for DMT frequency tones. As shown by the

solid lines, the available power may be sent to the initialization unit 306, which sends its output

to the pre-filtering unit 308, which sends its output to the repeated-bisection power splitting and

allocation unit 310. The actions taken in the units are as described below in the corresponding

method steps.

20   In one embodiment, the repeated-bisection splitting unit 310 may implement the

repeated-bisection of power scheme by: splitting the available power optimally between the

lower and the upper halves of a 1.104-MHz bandwidth to form two power fractions for two

substantially 552 KHz wide bands; splitting each of the two power fractions substantially

optimally between two halves of each of the substantially 552 KHz wide bands to form four

power fractions for four substantially 276 KHz wide bands; splitting each of the four power

fractions optimally between two halves of each of the four substantially 276 KHz wide bands to

5   form eight power fractions for eight substantially 138 KHz wide bands; splitting each of the

eight power fractions optimally between two halves of each of the eight substantially 138 KHz

wide bands to form sixteen power fractions for sixteen substantially 69 KHz wide bands;

splitting each of the sixteen power fractions optimally between two halves of each of the sixteen

substantially 69 KHz wide bands to form thirty-two power fractions for thirty-two substantially

10   34.5 KHz wide bands; splitting each of the thirty-two power fractions optimally between two

halves of each of the thirty-two substantially 34.5 KHz wide bands to form sixty-four power

fractions for sixty-four substantially 17.25 KHz wide bands; splitting each of the sixty-four

power fractions optimally between two halves of each of the sixty-four 17.25 KHz wide bands

to form one hundred twenty eight power fractions for one hundred twenty eight substantially

15   8.625 KHz wide bands; and splitting each of the one hundred twenty eight power fractions

optimally between two halves of each of the one hundred twenty eight, 8.625 KHz wide bands

to form two hundred fifty six power fractions to form two hundred fifty six substantially 4.3125

KHz wide bands.

Alternatively, the available power may be sent to the pre-filtering unit 308 first, whose

20   output is sent to the initialization unit 306, and the output of the initialization unit may be sent

to the repeated-bisection power splitting and allocation unit 310. In this embodiment, the

initialization unit 306 is coupled to the pre-filtering unit 308 which receives the available

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power, such that the initialization unit 306 receives notification of the bins that are flagged, and then calculates aggregate parameter values needed to implement the repeated-bisection of power scheme and excludes bins flagged by the pre-filtering unit.

In one embodiment, each of 2^j elements of a noise power vector to be used at step-j of

5   the repeated-bisection of power scheme may be calculated as a sum of noise power values in bins aggregated for the step-j, where j =1,...,8. Similarly, each of 2^j elements of a channel attenuation vector that is to be used at step-j of the repeated-bisection of power scheme may be calculated as an average of channel attenuation values in bins aggregated for step-j, where j =1,...,8. Also, each of 2^j elements of a power mask vector that is to be used at step-j of the

10   repeated-bisection of power scheme may be calculated as a sum of power mask values in bins aggregated for step-j, where j =1,...,8.

The available power may be selected to be allocated to 2^n tones where n is a preselected integer. Typically, in this embodiment, the initialization unit 306 initializes the modem by calculating aggregate parameter values of channel attenuation, noise power, and power mask for

15   n subsequent steps.

Figure 4 shows a method for allocation of an available power to Discrete Multi-Tone (DMT) frequency tones in a DMT-based Digital Subscriber Line (DSL) modem in accordance with the present invention. The method typically includes the steps of: initializing 402 the DMT-based DSL modem by calculating aggregate values of channel attenuation, noise power,

20   and power mask; pre-filtering 404 to flag noisy bins that are unable to support a minimum number of bits with a maximum power available for transmission in a bin; and using a repeated-bisection splitting scheme 406 to allocate the available power substantially optimally among a

plurality of bands for DMT frequency tones, wherein, where bins flagged in the pre-filtering process and not yet excluded are excluded by the scheme.

The method may implement the repeated-bisection splitting scheme by: splitting the available power optimally between the lower and the upper halves of a 1.104-MHz bandwidth to form two power fractions for two substantially 552 KHz wide bands; splitting each of the two power fractions substantially optimally between two halves of each of the substantially 552 KHz wide bands to form four power fractions for four substantially 276 KHz wide bands; splitting each of the four power fractions optimally between two halves of each of the four substantially 276 KHz wide bands to form eight power fractions for eight substantially 138 KHz wide bands; splitting each of the eight power fractions optimally between two halves of each of the eight substantially 138 KHz wide bands to form sixteen power fractions for sixteen substantially 69 KHz wide bands; splitting each of the sixteen power fractions optimally between two halves of each of the sixteen substantially 69 KHz wide bands to form thirty-two power fractions for thirty-two substantially 34.5 KHz wide bands; splitting each of the thirty-two power fractions optimally between two halves of each of the thirty-two substantially 34.5 KHz wide bands to form sixty-four power fractions for sixty-four substantially 17.25 KHz wide bands; splitting each of the sixty-four power fractions optimally between two halves of each of the sixty-four 17.25 KHz wide bands to form one hundred twenty eight power fractions for one hundred twenty eight substantially 8.625 KHz wide bands; and splitting each of the one hundred twenty eight power fractions optimally between two halves of each of the one hundred twenty eight, 8.625 KHz wide bands to form two hundred fifty six power fractions to form two hundred fifty six substantially 4.3125 KHz wide bands.

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Where the pre-filtering step 404 precedes the initializing step 402 (dashed lines), the initializing step 402 may provide for calculating aggregate parameters needed while excluding noisy bins that are flagged as unable to support a minimum number of bits with a maximum power available for transmission in a bin.

5   Each of 2^j elements of a noise power vector to be used at step-j may be calculated as a sum of noise power values in bins aggregated for the step-j, where j $=1,\dots,8$. Also, each of 2^j elements of a channel attenuation vector that is to be used at step-j may be calculated as an average of channel attenuation values in bins aggregated for step-j, where j $=1,\dots,8$. In addition, each of 2^j elements of a power mask vector that is to be used at step-j may be calculated as a sum of

10   power mask values in bins aggregated for step-j, where j $=1,\dots,8$.

Generally, the available power is allocated to 2^n tones where n is a preselected integer. Initializing typically includes calculating aggregate parameter values of channel attenuation, noise power, and power mask for n subsequent steps.

Clearly, the method of the invention may be implemented by digital signal processor, a

15   microprocessor, a general processor, or other circuitry arranged to implement the steps of the method.

The present invention may be implemented by a computer readable medium such as, for example, a memory, computer disk, or the like, having computer-executable instructions for allocation of an available power to Discrete Multi-Tone (DMT) frequency tones in a DMT-

20   based Digital Subscriber Line (DSL) modem, wherein the computer-executable instructions include the steps of: initializing the modem by calculating aggregate values of channel attenuation, noise power, and power mask; pre-filtering to flag noisy bins that are unable to

support a minimum number of bits with a maximum power available for transmission in a bin;

and using a repeated-bisection splitting scheme to allocate the available power substantially

optimally among a plurality of bands for DMT frequency tones. The exclusion of the flagged

bins may be accomplished in the initializing step or, alternatively, in the step of using the

5   repeated-bisection splitting scheme. Where desired, the repeated-bisection splitting scheme

may include the steps enumerated above.

Each of 2^j elements of a noise power vector to be used at step-j of the repeated-

bisection splitting scheme may be calculated as a sum of noise power values in bins aggregated

for the step-j, where j =1,...,8. Similarly, each of 2^j elements of a channel attenuation vector

10   that is to be used at step-j of the repeated-bisection splitting scheme may be calculated as an

average of channel attenuation values in bins aggregated for step-j, where j =1,...,8. Also,

each of 2^j elements of a power mask vector that is to be used at step-j of the repeated-bisection

splitting scheme may be calculated as a sum of power mask values in bins aggregated for step-j,

where j =1,...,8. The available power is generally allocated to 2^n tones where n is a preselected

15   integer. Initializing typically includes calculating aggregate parameter values of channel

attenuation, noise power, and power mask for n subsequent steps.

Although the present invention has been described in relation to particular preferred

embodiments thereof, many variations, equivalents, modifications and other uses will become

apparent to those skilled in the art. It is preferred, therefore, that the present invention be

20   limited not by the specific disclosure herein, but only by the appended claims.

What is claimed is:

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